Proc. NIPR Symp. Upper Atmos. Phys., 4, 42–50, 1991

CNA PULSATIONS ASSOCIATED WITH GEOMAGNETIC SUDDEN COMMENCEMENTS

Hiroshi NAGANO[1], Natsuo SATO[2] and Masaru AYUKAWA[2]

[1]*Department of Physics, School of Liberal Arts, Asahi University, 1851, Hozumi, Hozumi-cho, Motosu-gun, Gifu 501–02*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: In the cosmic radio noise absorption (CNA) data obtained by a riometer at Syowa Station, CNA pulsations were sometimes observed following geomagnetic sudden commencements (SC's). In order to investigate characteristics of the occurrence, 138 SC events were analyzed using 1-second CNA and geomagnetic data at Syowa Station from April 1981 to December 1986. Local time dependence can be seen in the SC-associated CNA pulsation (CNA Psc). The occurrence rate is highest in the morning and has a secondary peak before midnight, that is to say, it shows a marked dawn-dusk asymmetry. CNA Psc accompanies geomagnetic Psc at the time of strong CNA increase caused by large SC's with high pre-SC *AE* index. Furthermore, CNA Psc tends to be more correlated with the *H* component of magnetic Psc in the Psc 5 period range and the *D* component for shorter period in the Psc 4 range.

1. Introduction

Cosmic radio noise absorption (CNA) increases in association with geomagnetic sudden commencements (SC's) in and near the auroral zone. It is caused by an extra ionization in the lower ionosphere produced by energetic particle precipitation from the magnetosphere at the time of SC's (MATSUSHITA, 1962; ORTNER *et al.*, 1962; BROWN, 1978a, b). On the other hand, CNA often exhibits quasi-periodic fluctuations (CNA pulsations) associated with magnetic pulsations (ROSENBERG *et al.*, 1979; OLSON *et al.*, 1980; SATO *et al.*, 1985; OKSMAN *et al.*, 1988; KIKUCHI *et al.*, 1988; HIGUCHI *et al.*, 1988). OLSON *et al.* (1980) reported that CNA pulsation propagates in the same direction as Pc 5 geomagnetic pulsation, and suggested that the variations in electron precipitation causing the CNA pulsation are controlled by the ULF magnetic pulsation through ULF-VLF-electron precipitation. SATO *et al.* (1985) reported that CNA pulsations with the period of 10–500 s are observed mostly during morning hours, most of them being associated with magnetic pulsations and quasi-periodic VLF emissions, and they are more correlated with the *D* component of magnetic pulsations than the *H* component. HIGUCHI *et al.* (1988) showed that CNA pulsations tend to be more correlated with the *H* component of Pc 3–5 magnetic pulsations rather than the *D* component. Recently, KIKUCHI and YAMAGISHI (1989) showed a distinct latitudinal dependence of CNA associated with an SC and subsequent substorm by using a scanning beam riometer constructed at Syowa Station.

NAGANO *et al.* (1989) introduced that increase in SC-associated CNA is expressible as a function of the following parameters:

$$f(\text{MLT, pre-SC condition}, \Delta H, \Delta H/\Delta T)\,.$$

Here, MLT denotes magnetic local time, and pre-SC condition means the condition of fields and particles in the magnetosphere and ionosphere before SC onset. AE index or Dst index is used to represent the pre-SC condition. ΔH and ΔT indicate SC amplitude and rise time in the H component of magnetic field in the magnetopshere or on the ground, respectively. ΔH and ΔT will depend on the characteristics of interplanetary shocks or discontinuities, and the magnetospheric response. They reported that a local time dependence exists in the CNA occurrence rate and average intensity of CNA increase, and a strong absorption occurs at the time of large pre-SC AE index, ΔH and $\Delta H/\Delta T$, from a statistical examination of riometer and geomagnetic data at Syowa Station. In the present paper we study statistical characteristics of the occurrence of CNA pulsations associated with SC's using 1-second riometer and geomagnetic data obtained at Syowa Station. CNA intensity and magnetic pulsation amplitude are also used in addition to the above-mentioned parameters in order to clarify the characteristics.

2. Data Analysis

The characteristics of CNA pulsations associated with SC's (CNA Psc) are statistically studied with 1-second digital riometer and geomagnetic data obtained at Syowa Station from April 1981 to December 1986. Syowa Station in Antarctica is located at 66.1°S and 70.8°E in the geomagnetic coordinates. The magnetic local time (MLT) at Syowa Station is the universal time (UT) plus 6 min. The events reported as an SC in "Solar Geophysical Data" (H. E. COFFEY, ed.) were examined in this study. The number of available events was 138 in the period examined. Some typical CNA Psc's are demonstrated in Fig. 1. As shown in Fig. 1(a), CNA was intensified after the onset of an SC and CNA pulsation with the period of about 3.2 min can be seen in the intensified CNA. The magnetic variations observed with a fluxgate magnetometer indicate Psc pulsation. In particular, the H component has the same period as the CNA pulsation and is in phase with it. Figure 1(b) also shows large-amplitude CNA and magnetic pulsations associated with an SC. The CNA Psc has the period of about 5.9 min and is in phase with the H and Z components of fluxgate magnetic data. Figure 1(c) also represents CNA and magnetic Psc's. Magnetic fluctuations existed before SC onset and magnetic pulsations with the period of about 2.7 min occurred after the onset. CNA data also indicates Psc pulsation with the same period, which is out of phase with the magnetic D component. Figure 1(d) shows a CNA intensified strongly after SC onset without CNA pulsation.

A relationship between the CNA Psc and the magnetic Psc was examined, and the local time dependence of the occurrence rate is summarized in Fig. 2. The local time distribution of the occurrence of the 138 SC's examined is indicated in the upper panel. The number of SC's during each 3-hour interval is from 12 to 23. As shown

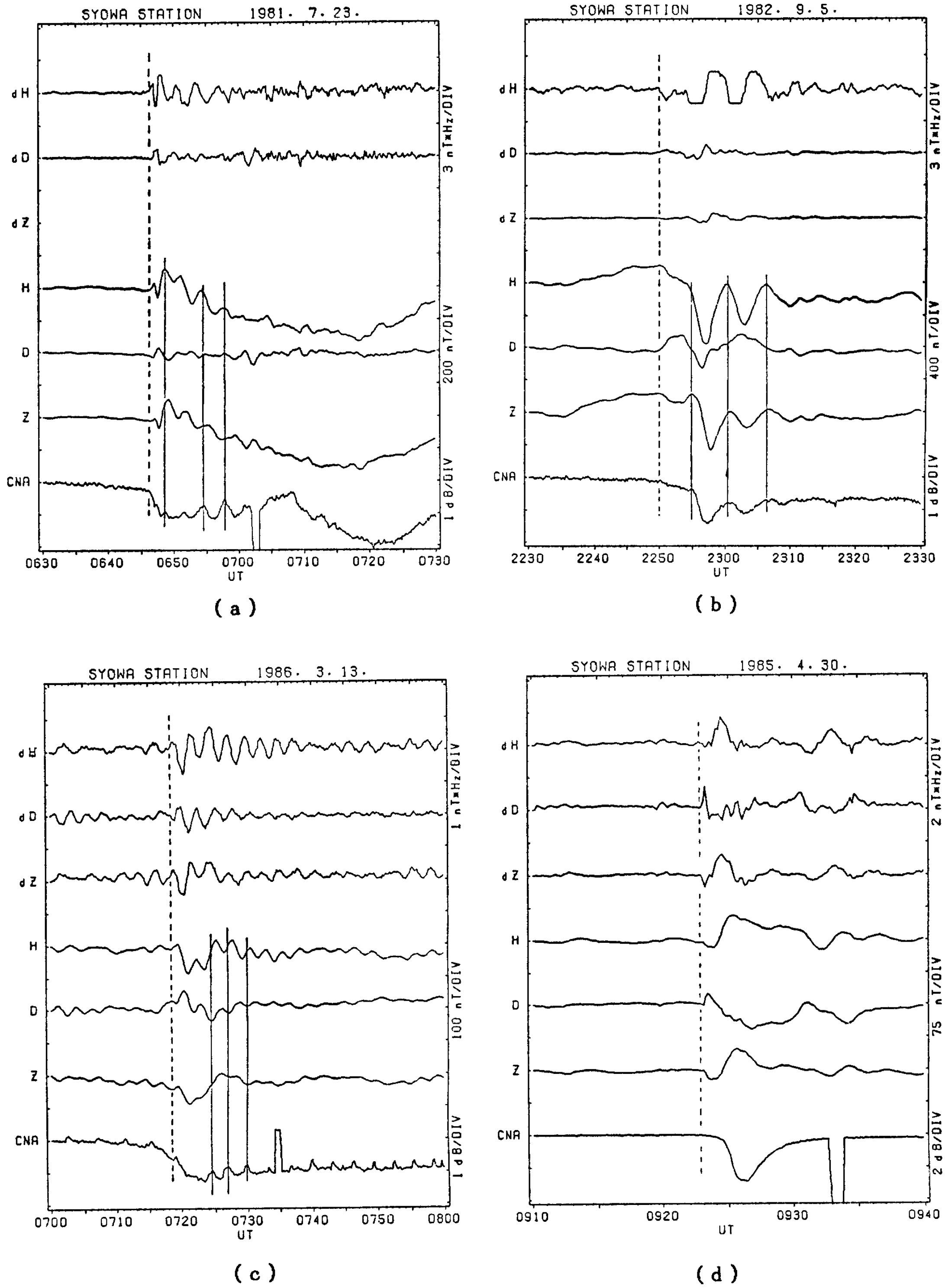

Fig. 1. Magnetograms of three components dH, dD and dZ of ULF by an induction magnetometer, three components H, D and Z of magnetic field by a flux gate magnetometer, and riometer data at 30 MHz observed at Syowa Station. (a) indicates data for an SC at 0646 UT on July 23, 1981; (b) for an SC at 2250 UT on September 5, 1982; (c) for an SC at 0718 UT on March 13, 1986; (d) for an SC at 0923 UT on April 30, 1985.

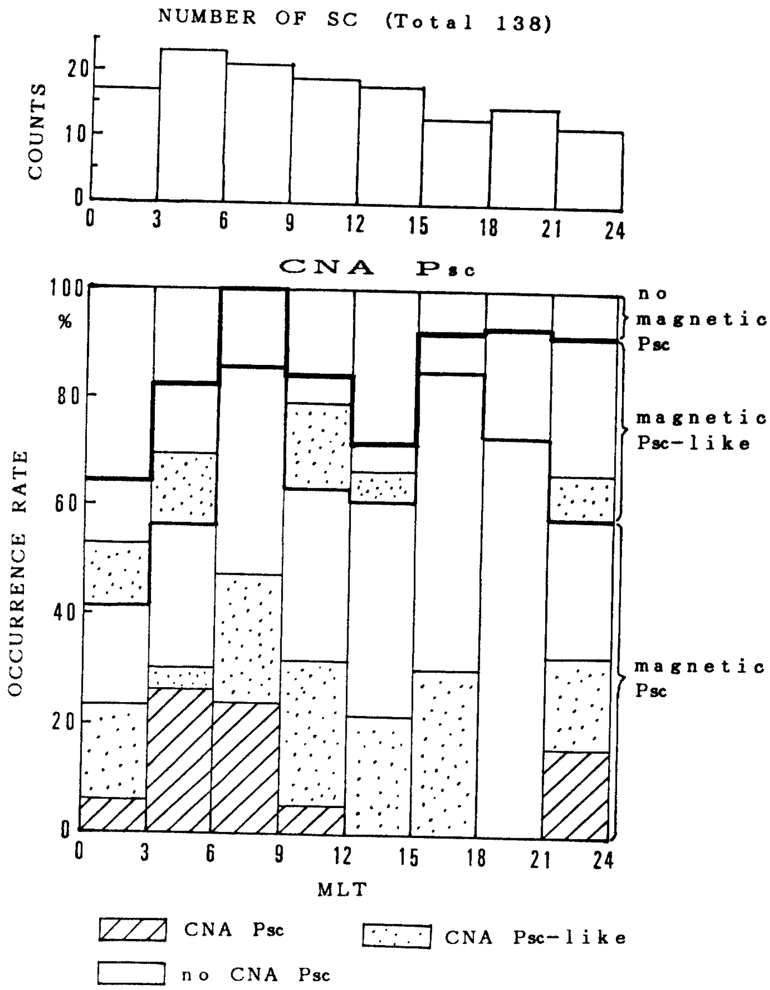

Fig. 2. Magnetic local time dependence of the occurrence of the total 138 SC's observed at Syowa Station (upper penel) and the occurrence rate of CNA Psc with relation to magnetic Psc occurrence (lower panel).

in the lower panel of Fig. 2, the CNA Psc occurrence rate is classified with reference to the magnetic Psc occurrence. CNA Psc-like and magnetic Psc-like events do not show clear waveform with monochromatic period but the mixture of some waveforms with various periods. As a whole the occurrence rate is about 11% for CNA Psc and about 32% including CNA Psc-like events. The occurrence rate of CNA Psc has the largest peak during 3–9 h MLT and a secondary peak during 21–24 h MLT. Furthermore, CNA Psc appears only when magnetic Psc occurs. The tendency is the same even if CNA Psc-like events are included. In the absence of magnetic Psc, both CNA Psc and Psc-like events do not appear. There does not exist a clear dawn-dusk asymmetry with regard to magnetic Psc, while CNA Psc has a marked dawn-dusk asymmetry.

As CNA Psc occurs predominantly during 3–9 h MLT, the occurrence condition for 21 SC events in the time period was examined with regard to several parameters. Figure 3(a) shows the dependence on CNA intensity and pre-SC $\overline{AE}(6)$ (6 hour-averaged AE index before SC onset) of CNA Psc. CNA Psc tends to occur when both CNA

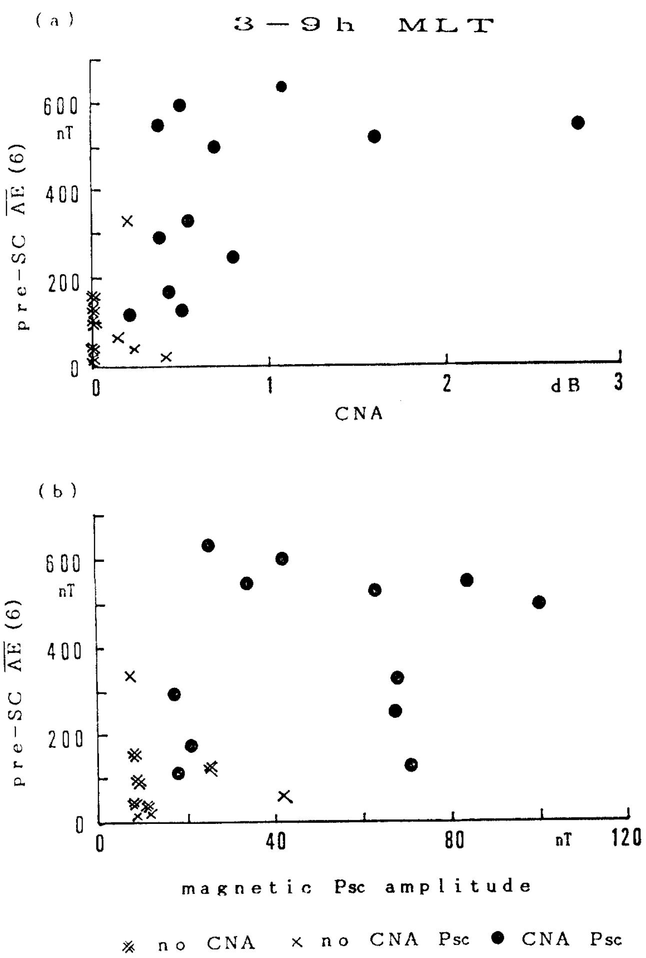

Fig. 3. Diagrams of the occurrence of CNA and CNA Psc events taking 6 hour-averaged AE index before SC onset (pre-SC $\overline{AE}$ (6)) in the ordinate, and (a) CNA intensity and (b) magnetic Psc amplitude in the abscissa for 21 SC events occurred during 3–9 h MLT. Double-cross signs, cross signs and circles denote no CNA, no CNA Psc and CNA Psc events, respectively.

and pre-SC $\overline{AE}(6)$ are large, that is to say, always when CNA intensity is greater than 0.5 dB and pre-SC $\overline{AE}(6)$ is greater than 350 nT. Figure 3(b) shows the dependence on magnetic Psc amplitude and pre-SC $\overline{AE}(6)$ of CNA Psc. It can be seen from this figure that CNA Psc occurs when both magnetic Psc amplitude and pre-SC $\overline{AE}(6)$ are larger, that is to say, always when magnetic Psc amplitude is greater than 45 nT and pre-SC $\overline{AE}(6)$ is greater than 350 nT. In other words, CNA Psc does not occur in the case of small pre-SC AE index even when magnetic Psc has a certain measure of amplitude and also in the case of small amplitude of magnetic Psc even when pre-SC AE index is large to a certain extent. Furthermore, as shown from both figures, it is necessary for the occurrence of CNA Psc that magnetic Psc appears with the amplitude greater than 20 nT when SC-associated CNA increase is stronger than 0.5 dB. Figure 4(a) and (b) show the dependence on magnetic SC amplitude (ΔH) and ratio of SC amplitude to rise time ($\Delta H/\Delta T$), respectively, at Honolulu (21.4°N; 270.0°E in the geomagnetic coordinates) with regard to the CNA Psc for the same SC events. It can

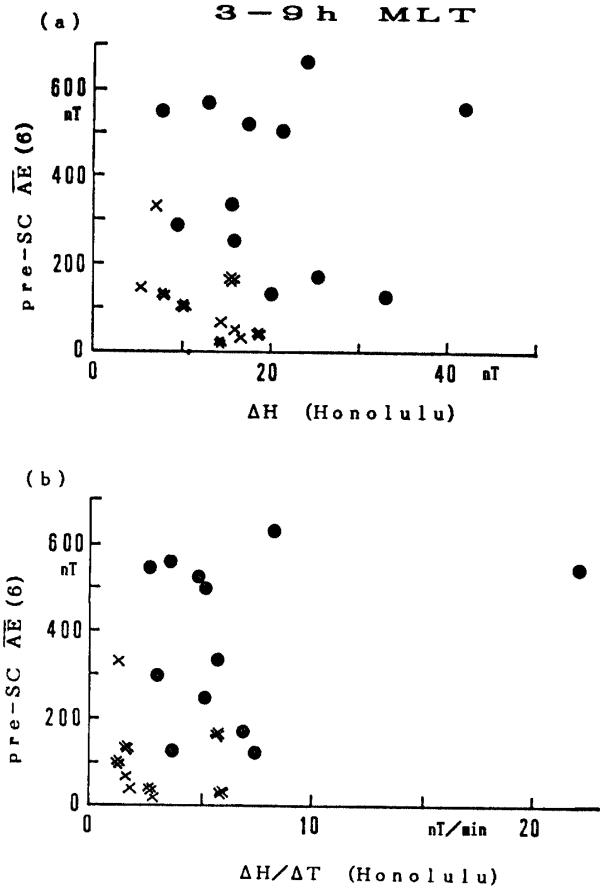

Fig. 4. Diagrams of the occurrence of CNA and CNA Psc events taking pre-SC $\overline{AE}$(6) in the ordinate, and (a) magnetic SC amplitude (ΔH) and (b) the ratio of SC amplitude to rise time ($\Delta H/\Delta T$), at Honolulu in the abscissa for the same SC events.

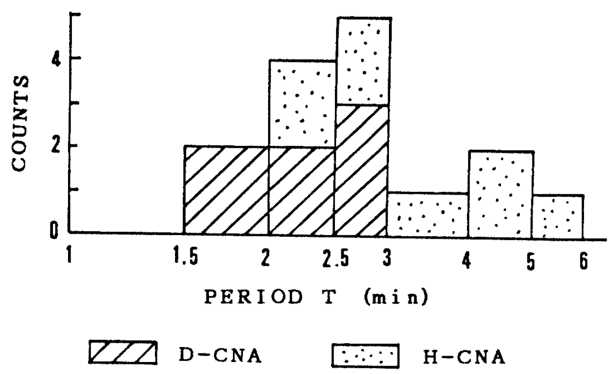

Fig. 5. Period distribution of CNA Psc clarified by the component H or D of magnetic Psc with good correlation.

be seen from these figures that CNA Psc occurs always when ΔH is greater than 20 nT, $\Delta H/\Delta T$ is greater than 6 nT/min and pre-SC $\overline{AE}$(6) is greater than 350 nT.

A statistical distribution of the CNA Psc periods is shown in Fig. 5. CNA Psc with the period of 3–6 min (Psc 5 range) tends to show correlation with the H component of magnetic Psc having the same period. On the other hand, CNA Psc with the period of 1.5–2 min (shorter period in Psc 4 range) tends to be more correlated with the D component of magnetic Psc having the same period rather than the H component.

3. Discussion

Local time dependence can be seen in the occurrence rate of CNA Psc as shown in Fig. 2. It has the largest peak during 3–9 h MLT and a secondary peak during 21–24 h MLT. The occurrence rate of SC-associated CNA increase is highest near midday and shows a secondary small peak near midnight (NAGANO *et al.*, 1989). Thus, CNA Psc has a marked dawn-dusk asymmetry, while CNA increase has a day-night asymmetry. There does not exist a clear dawn-dusk asymmetry for the occurrence rate of magnetic Psc as shown in Fig. 2. Furthermore, magnetic Psc 4–5 observed by geostationary satellites in the magnetosphere also does not indicate a clear dawn-dusk asymmetry (NAGANO and ARAKI, 1985). It is interesting that there appears a dawn-dusk asymmetry for CNA Psc resulted from the modulation in electron precipitation by magnetic Psc, which dose not show any dawn-dusk asymmetry. Similar asymmetry can be seen in the occurrence rate of CNA pulsation with the period of 10–500 s (SATO *et al.*, 1985). CNA Psc occurring predominantly in the morning is probably due to a magnetic Psc modulation for the precipitation of daytime magnetospheric electrons into the ionospheric D region by pitch angle diffusion from the magnetosphere following its sudden contraction. On the other hand, CNA Psc near midnight is considered to be due to a magnetic Psc modulation for the precipitation of electrons from the magnetospheric tail, in association with SC-triggered substorms.

In the daytime SC-associated CNA increase tends to appear when ΔH, $\Delta H/\Delta T$ at Honolulu and pre-SC AE index are larger (NAGANO *et al.*, 1989). This condition is similar for the occurrence of CNA Psc as shown in Figs. 3 and 4. Moreover, it is necessary that magnetic Psc appears with the amplitude greater than 20 nT when SC-associated CNA increase is stronger than 0.5 dB. Therefore, CNA Psc is considered to occur accompanying magnetic Psc at the time of strong CNA increase caused by large SC's with high pre-SC AE index.

CNA Psc tends to be more correlated with the H component of magnetic Psc in the Psc 5 period range, whereas rather with the D component for shorter period in the Psc 4 range, as shown in Fig. 5. SATO *et al.* (1985) reported that CNA pulsations with the period of 10–500 s are more correlated with the D component of magnetic pulsations than the H component. On the other hand, HIGUCHI *et al.* (1988) showed that CNA pulsations tend to be more correlated with the H component of Pc 3–5 magnetic pulsations than the D component. Although there is such a discrepancy for CNA pulsations, CNA Psc tends to show good correlation with each different component of magnetic Psc for longer and shorter periods in the Psc 4–5 range. When an interplanetary shock or discontinuity collides with the magnetosphere, the dawn-to-dusk magnetopause current is enhanced and the magnetic field in the magnetosphere begins to increase. This increase propagates toward the earth as a compressional hydromagnetic wave. The inhomogeneity of the plasma and magnetic field in the magnetosphere produces the conversion from the compressional wave to a transverse wave (TAMAO, 1964). The transverse wave is transmitted to the polar ionosphere along magnetic lines of force. The toroidal mode of the transverse wave oscillates predominantly in the longitudinal direction and the poloidal mode in the radial direction in the magnetosphere. As the polarization axis of Alfvén mode waves rotates by 90° during passage through the ionosphere by the screening effect (NISHIDA, 1964; HUGHES and SOUTHWOOD, 1976), the toroidal mode in the magnetosphere is considered to be related with the *H* component of magnetic Psc on the ground. Therefore, if the electron precipitation is modulated by the transverse wave, good correlation can be expected between CNA Psc and the *H* component of magnetic Psc in the Psc 5 period range on the ground. On the other hand, as the radial component of the poloidal mode in the magnetosphere probably corresponds to the *D* component on the ground, CNA Psc is expected to be more correlated with the *D* component of magnetic Psc for shorter period in the Psc 4 range. Similar explanation was given for the correlation between CNA pulsation and magnetic Pc pulsation by HIGUCHI *et al.* (1986). It will be necessary to examine the coherence and phase difference between CNA Psc and magnetic Psc for more precise investigation.

References

BROWN, R. R. (1978a): On the poleward expansion of ionospheric absorption regions triggered by sudden commencements of geomagnetic storm. J. Geophys. Res., **83**, 1169–1171.

BROWN, R. R. (1978b): On sudden commencement absorption events at the south pole and their relation to the latitude of the lower cleft boundary. J. Geophys. Res., **83**, 2205–2207.

HIGUCHI, Y., SHIBUYA, S. and SATO, N. (1986): CNA pulsations associated with Pc 3–5 magnetic pulsations. Mem. Natl Inst. Polar Res., Spec. Issue, **42**, 58–66.

HIGUCHI, Y., SHIBUYA, S. and SATO, N. (1988): CNA pulsations accompanying hydromagnetic waves at conjugate stations. Planet. Space Sci., **36**, 1255–1267.

HUGHES, J. W. and SOUTHWOOD, D. J. (1976): An illustration of modification of geomagnetic pulsation structure by the ionosphere. J. Geophys. Res., **81**, 3241–3247.

KIKUCHI, T. and YAMAGISHI, H. (1989): Latitudinal features of cosmic noise absorption at the time of SSC-triggered substorm as observed with scanning beam riometer. Proc. NIPR Symp. Upper Atmos. Phys., **2**, 9–14.

KIKUCHI, T., YAMAGISHI, H. and SATO, N. (1988): Eastward propagation of Pc 4–5 range CNA pulsations in the morning sector observed with scanning narrow beam riometer at L=6.1. Geophys. Res. Lett., **15**, 168–171.

MATSUSHITA, S. (1962): On geomagnetic sudden commencements, sudden impulses, and storm durations. J. Geophys. Res., **67**, 3753–3777.

NAGANO, H. and ARAKI, T. (1985): A statistical study on Psc 4 and Psc 5 observed by geostationary satellites. Planet. Space Sci., **33**, 365–372.

NAGANO, H., ARAKI, T., IYEMORI, T., SATO, N. and AYUKAWA, M. (1989): Characteristics of CNA associated with geomagnetic sudden commencements. Proc. NIPR Symp. Upper Atmos. Phys., **2**, 15–24.

NISHIDA, A. (1964): Ionospheric screening effect and storm sudden commencement. J. Geophys. Res., **69**, 1861–1874.

OKSMAN, J., ROSENBERG, T. J., LANZEROTTI, L. J., MACLENNAN, C. G. and SINGER, H. J. (1988): Study of a conjugate Pc 5–6 magnetic and absorption pulsation event at subauroral latitudes in the morning sector. J. Geophys. Res., **93**, 5589–5599.

OLSON, J. V., ROSTOKER, G. and OLCHOWY, G. (1980): A study of concurrent riometer and magnetometer variations in the Pc 4–5 pulsation band. J. Geophys. Res., **85**, 1695–1702.

ORTNER, J., HULTQVIST, B., BROWN, R. R., HARZ, T. R., HOLT, O., LANDMARK, B., HOOK, J. L. and LEINBACH, H. (1962): Cosmic noise absorption accompanying geomagnetic storm sudden commencements. J. Geophys. Res., **67**, 4169–4186.

ROSENBERG, T. J., LANZEROTTI, L. J. and MACLENNAN, C. G. (1979): Impulsive, quasi-periodic variations in the ionospheric absorption of cosmic radio noise. J. Geomagn. Geoelectr., **31**, 585–597.

SATO, N., SHIBUYA, S., MAEZAWA, K., HIGUCHI, Y. and TONEGAWA, Y. (1985): CNA pulsations associated with quasi-periodic VLF emissions. J. Geophys. Res., **90**, 10968–10974.

TAMAO, T. (1964): A hydromagnetic interpretation of geomagnetic SSC*. Rep. Ionos. Space Res. Jpn., **18**, 16–31.

(Received August 2, 1990; Revised manuscript received November 13, 1990)